Risks in production and the management of labour

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SOM theme A: Structure, Control and Organization of Primary Processes

Abstract

The history of the risk management profession shows increasing specialization within disciplines. In organizations this specialization is often institutionalized in different (sub)departments each one taking into account different types of risk. As a result the interrelations between these risks are neglected and therewith the question arises who will manage the specialists. Further, an inventory of these specializations shows that theory formulation and empirical research regarding the relationship between risks, the organization of production and the management of labour is underdeveloped. This paper presents a theoretical and empirical perspective which could serve as a starting point for research in this domain of risk management.

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1. Introduction

The assessment and control of risks is not a domain invented in the 20th century. In the Netherlands the systematic study of risk assessment and risk accounting started as early as the 17th century and is strongly associated with Johan de Witt who elaborated mathematical methods to estimate life expectancies related to the accounting of life insurance premiums. As risk can be defined as an uncertain situation in which a number of possible outcomes might occur, one or more of which is undesirable,[1] risk assessment and risk management have in various degrees always been part of the very nature of entrepreneurial activity. In the literature such ’entrepreneurial risks’ are usually referred to as *speculative risks* because they can be identified with both the probabilities of profit and loss. Contrary to speculative risks *pure risks* involve only the probability of losses.[2]

In this article the emphasis is on pure risks, notably those which originate from the organization of primary production processes. Such risks cover a wide range of potential effects varying from a simple breakdown of a production line till and including spectacular events like the explosion of chemical plants and the resulting pollution of the environment. In both cases companies have to pay a price and therefore have an interest in preventing such events from happening.

In the following sections we will concentrate on the management of risks originating at the shopfloor level. Although the study of risk has specialized along different disciplinary lines sofar the study of risk related to the organization of labour is not well represented. This is remarkable, not only because in many cases human failures are at the heart of the explanation of production breakdowns, but also because in the field of labour organization theories are now available that enable us to a better understanding of such risks.

In section two a short history of risk management is presented. This history is characterized by an emphasis on specialization and an one-sided conception of rationality, topics to be treated in respectively the sections three and four. In section five the attention is directed to the organizational context, especially the problem of the management of complexity. The idea that Modern Socio-Technical theory (MST) can contribute to effective risk management is developed in section six. To illustrate our theoretical viewpoints, in section seven we shortly report on a study of risk in chemical process industry. In section eight some conclusions are drawn with regard to the future of risk management.

2. The Origins of Risk Management

In the 1960's the concept of risk management as such was introduced in the US. Foremost it was associated with insurance. US enterprises felt their environments to become more complex and dynamic. Consequently, the number of risks increased while at the same time the understanding of the nature of these risks decreased. As a result damages increased and therewith the number of claims on insurance companies. The latter reacted by augmenting insurance premiums.[3] In order to control and manage their insurances business firms attracted a new kind of manager, the insurance manager, responsible for the insurance portfolio of the firm. As many of the risks large enterprises faced, turned out to be not longer insurable or too costly to insure, the perspective of the insurance manager gradually enlarged: next to insuring possible damage, the prevention of damage became a profitable and often necessary alternative. Gradually the term insurance manager changed into risk manager.[4]

Since its origins the domain of risk management thus was strongly related to insurance and owes its main concepts and methods mainly from this perspective. Within this frame of reference disciplines like probability theory, economics, operational research, systems theory and decision theory contributed substantially to the study of risks. Bannister and Bawcutt refer to these five disciplines as the 'main sources of risk technology'.[5] To these the domains of psychology and finance should be added.

Probability theory is at the heart of traditional risk assessment as it developed within the domain of insurance. Its major advantage is that it enables to quantitative risk-benefit analysis. The introduction of powerful computers has significantly broadened the scope and possibilities of probabilistic risk assessment. However, the essential weakness of probabilistic risk assessment is that computing can only be done if data are available to feed the machine with. I.e., one must have *on beforehand* some ideas of the nature of the risks involved. These can be attained either by the analysis of past experiences, by simulation, by game theory or by making up scenarios.

Associated with risk management the central issue in economics is on decision making under conditions of uncertainty. In this respect economic thinking is related to probability theory and risk-benefit analysis. A major assumption of economic theory is the ’Expected Utility Hypothesis’: a decision maker seeks a maximalization of the expected value of an utility. According to the hypothesis a risk is then dependent on the degree of deviation from the expected value and the probability of this deviation to occur.[6] Consequently, the attitude of the decision maker towards a certain risk can be presented as a function of preference. In the recent past many economists criticized this theory because it starts from an unrealistic assumption of rationality. Notably Herbert Simon pointed to the fact that rationality is bounded. A decision maker is unable to know all information and data needed, to know all alternatives possible as well as their outcomes. As a result decision makers can never reach a maximum utility and have therefore to accept a lower level of satisfaction than the theoretically postulated maximum.[7]

The development of Management Information Systems (MIS) and Decision Support Systems (DSS) certainly was an advancement to reduce the problem of bounded rationality, although it did not solve the latter fundamentally. Such systems consist of computer software which structure problems and information. Advanced powerful computers undoubtedly can handle complex information better than the human mind. However, the output still remains dependent on the input. Besides, computer programs fail to take into account ’the element of knowledge and thinking that is beyond logical analysis (and which) is covered by such indefinable quantities as personal style, taste, intuition and good feeling, the fundamental indicators of tacit knowledge’.[8]

Psychologists have put forward that probability theory and statistical decision science can only produce a partial approach to risk assessment precisely because they fail to take into account the human element in decision making.[9] Thus March and Shapira argumented that risks can be defined in many ways and that the definition chosen determines which decision rule will be applied and therewith the outcome of the process of decision making.[10] In a study by MacCrimmon and Wehrung it is concluded that managers' perceptions of risks substantially deviate from the rules of decision science: managers focus primarily on the amount of a potential loss while not taking into account the probability of occurrence of that loss. This implies that a risk involving a small potential loss, but with a high probability of occurrence is perceived as an acceptable risk while actually the damages can be very high as the risk will frequently occur.[11]

The history of risk management as summarized in the former section leads to some conclusions. The development of risk management led to specialization and a division of labour along the lines of different disciplines and is dominated by a specific concept of rationality. With the exception of psychology, most disciplines that focus on risk largely neglect human behaviour and the effects of the organizational context on that behaviour.

3. Specialization and Risk Management

The development of risk management as a science mainly developed *within* separate disciplines. In the professional domain this led to specialization, or, to put it in other words, to a division of labour between disciplines. One of the results of this specialization along different lines is the present vagueness and ambiguity of the terms risk management and risk manager.

A more serious effect is that in large enterprises this division of labour of specialists induced an institutionalization of risk management in different departments within the same firm. Such a split and compartmentalization of risk management blocks a functional communication between specialists and promotes a particularistic approach. The resulting difficulties to coordinate the specialists may create new risks which often turn out to be unmanageable given the context of particularism.

In the literature one can find many descriptions of the disastrous effects of such coordination failures. The most illuminating one is Medvedev's analysis of the Chernobyl disaster.[12] His main thesis is that the explosion of the nuclear reactor was not due to poor technology alone, but must be explained from the interaction between subsystems of which the technological subsystem is only one. Other factors contributing to the catastrophe were inadequate training of operators and staff, poor communications, long hierarchical lines, a culture of ritualism and secrecy provoked by the centralized Soviet system, the shared responsibility for the nuclear plant by rival ministries in Moscow and a reward system for the plant managers that latently stimulated a disregard of safety regulations.[13]

Studies of catastrophes like Medvedev's show that a crisis can seldom be explained by one causal factor. The origins of crises that jeopardize the functioning or even the very existence of systems should be found in an in time unique interplay of several factors. It is the simultaneous and interdependent function of such factors from which we can understand why things sometimes go wrong. This holds not only for major crises like the Chernobyl disaster, but also for the breakdown of production systems.

It may be clear that specialization within separate disciplines is a necessary, but not a sufficient condition for effective risk management. What is presently lacking is an approach which enables us to effectively integrate the knowledge available.

4. The Concept of Rationality

A second conclusion we can draw from the history of risk management is that it is based on a strong belief in rationality. One may wonder why despite the almost daily presentation of risk management's failures in the media there is still left a strong belief in the human potential to control risk. According to Berting this optimism should be associated with the cultural history of industrialism itself. It is the heritage of the Enlightenment with its emphasis on the replacement of the traditional order by one based on the rules of a positivist logico empirical science.[14] In the resulting conception of the social order absolute rationality is a keyword. Science, technology and industrialism are supposed to be able to expand man's control over his social and natural environment and to solve his major problems. Of course, the development of science and technology may be temporarily blocked by political and religious constraints, in the long run, however, rationality will overcome[15].

The predominance of the idea of rationality in Western culture has had a major impact on the ways we deal with risks in our organizations and in society. Firstly, risks can be controlled and managed or at least their consequences can be mitigated. Thus the very problems that are created by modern technology are believed to be solvable by technology itself. Secondly, as quantification is considered to be a prerequisite to scientific rationality, risk assessment has become dominated by quantitative methods, notably probabilistic risk assessment and risk-benefit analysis. As said before, this implies that one must have *on beforehand* some ideas of the nature of the risks involved. These can be attained either by the analysis of past experiences, by simulation, by game theory or by making up scenarios. Quantitative risk assessment methods seem to be based on the assumption that the unknown can be known.

Thirdly, in turn the closed system approach of quantitative risk assessment strengthened the traditional ideas of rational organization: unpredictable man has to be made predictable and controllable. There seem to be two strategies to reach this ideal. The first one is to substitute as many functions of human labour as possible by machine operations. What is left can be controlled by the second strategy, i.e.

bureaucratic organization: the application of hierarchical control associated with specialization, training, the establishment of well defined rules and regulations and the execution of proper sanctions.

The idea that specialization and bureaucratization lead to an increase of rationality and therewith to a more effective control of risks is at least one-sided. As is argumented below, such a type of rationalization increases system complexity and affects systems controllability.

Increasing specialization and bureaucratization do not per se mean that systems have become more rational. They imply, however, a shift in the *nature* of rationality. Building on the works of Simmel, Pareto and Weber,[16] Karl Mannheim made the distinction between substantial and functional rationality. An action is substantially rational if it reveals an intelligent insight into the interrelations of events in a given situation. An action is functionally rational if it relates to a definite goal and if it involves consequent calculation in order to reach that goal.[17] Thus, substantial rationality has to do with the ability to understand the pattern of interdependencies in a situation, while functional rationality comes close to Weber's concept of instrumental rationality (Zweckrationalität).[18] The historical trend of modernization and the concomitant processes of differentiation, specialization and bureaucratization caused a growing complexity of social relations in society at large.[19] Consequently, substantial rationality decreased while at the same time functional rationality increased. According to Mannheim this development has led to a situation in which

> '... the thinking out of a complex series of actions is confined to a few organizers ... A few people can see things more and more clearly over an ever widening field, while the average man's capacity for rational judgement steadily declines once he has turned over to the organizer the responsibility for making decisions.'[20]

The shift from substantial to functional rationality as a response to increasing complexity means that more and more people act on the basis of a restricted means-to-end rationality. However, what seems rational to the individual acting in a functionally rational way, may at the same time be irrational when viewed from the perspective of substantial rationality or from the perspective of another actor acting from a different position in the organization.

One of the effects of this functionally rational response to problems of complexity may be that the organization becomes ever more diffuse for the individuals participating in it. Therewith the chances of ambiguous information and ineffective communication are multiplied.[21] According to Wagenaar the causes of many a disaster can be reduced to cognitive failures, i.e. failures to process information properly. Bureaucratization and specialization induce 'rule-based errors' and 'knowledge- based errors', the former originating from contradictory rules and procedures, the latter from a restricted and false understanding of the situation at hand.[22] So *per se* rational action may induce risks if it is acted on in isolation without reference to the complexity of the whole in which it evolves.

In the frame of our analysis of the relation between rationality, risk and management, ritualistic conformity as a defense response should be emphasized too. Already as early as the 1950's Robert K. Merton pointed to this effect of bureaucratic rationality.[23] If the bureaucrat is confronted with unforseen situations to which the rules do not apply, he will react inadequately and in a ritualistic way by sticking to the rules. In two respects this response is defensive. Firstly, under the condition of a lack of substantial rationality, for many in the lower ranks of the organization rules are the only frame of reference to derive feelings of certainty from in unknown and unanticipated situations. Secondly, people working in bureaucratic organizations are submitted to sanctions if they violate the formal rules. Even if things go completely wrong because one sticks to the rules, for the individual rule conformity is the safest way to prevent the application of negative sanctions upon him. In this sense bureaucratic rules and procedures should not only be understood as mechanisms of social control but also as means that protect the worker from the whims of management.[24]

According to Mannheim only those in key positions are able to tie the diversity of functionally rational actions together and synthesize them on the higher level of substantial rationality. Hence, a major question is whether or not those in power are actually able to control actions of individuals and groups within the organization in such a way as to prevent substantial rationality of the system as a whole to be violated. This focuses our attention to the role of management because it is management that shapes and guides the organization and thus could counteract negative tendencies of functional rationality therewith promoting effective risk management.

However, usually managers do not react in such a way. Instead their inbuilt cultural reflexes urge them to further strengthening bureaucratic control. This phenomenon is called the ’vicious circle of bureaucracy’: rational bureaucratic control evokes problems that are reacted to by the establishment of new ’rational’ rules that will evoke new problems, and so on. This process of ever increasing functional rationality will gradually weaken the control over the organization instead of enhancing it. There are two arguments that make this process understandable.

First of all, rationalization and bureaucratization of production systems have led to a separation of production control and production itself. So most current production systems in the Western world contain two separated subsystems: the control system and the production system. The control system fulfils the functions of administration, development, planning and control. It regulates the production system which is exclusively oriented towards the execution of production tasks and has no self-regulating capacity. Because of the split between control and production, control of the system as a whole suffers as it is under these conditions not possible for the production system to react directly to unforeseen variations and disturbances that occur in the production process.

Secondly, decades of production rationalization along these lines have resulted in a fragmentation of tasks within both the production system and the control system. As the fragmentation of tasks within the production system increases, so does the need for control. However, increasing differentiation within controlling subsystems has led to bureaucratization and struggles about competence that prevent the execution of effective system monitoring, control and problem solving.

The separation between control and production and the fragmentation within both the control and the production system lead to the vicious circle mentioned before: new problems are responded to by increasing differentiation and consequently effectuate further fragmentation and a progressive widening of the gap between control and production therewith continuously decreasing the controllability of the system as a whole.[25]

Therefore, we may conclude that in systems which develop according to the path described above, the need for control ever increases while the control capacity continuously decreases. We may therefore expect that the conditions for effective risk management deteriorate gradually and that the probabilities of actual crises will proportionally enlarge.

5. Complexity, Organization and Risk

From the above analysis it follows that organizational complexity is one of the major sources of risks. The problems arising from this complexity can not be solved by an isolated analytical emphasis on specific parts or functions. Ackoff therefore pleas for a design oriented perspective based on an integrative holistic approach.[26] Such a perspective does not so much concentrate on an in depth analysis of subsystems and their parts within the organization as well as on the *interaction* of parts and subsystems *within* the context of the organization as a whole. In its turn the organization should be conceived of as an open system interacting with the environment. In 1984 Charles Perrow published a book on the relation between the complexity of organizations and their catastrophic potentials.[27] The title of this book, 'Normal Accidents', points to Perrow's main thesis that for some types of organizations accidents are normal given the organizational characteristics. Perrow distinguishes two pairs of variables that should be thought of as continua: complex versus linear systems and tightly versus loosely coupled systems. Linearity, complexity, loose and tight coupling are system characteristics which determine the occurrence and nature of risks.

Linear systems are characterized by linear interactions: 'Linear interactions are those in expected and familiar production or maintenance sequence, and those that are quite visible even if unplanned'.[28] A simple example of a linear system is the traditional assembly line. The work stations are placed in a linear and logical sequence. The number of units that shape the total line is unimportant: in all cases of failure the source of the malfunction can be easily spotted. It is relatively simple to estimate the effects of a potential crisis in such systems and to design a line of action to neutralise potential risks. Most interactions in industrial production systems are of the linear type.

Risk management becomes more complicated if parts, units or subsystems fulfil multiple functions:

> ’For example, a heater might heat both the gas in tank A and also be used as a heat exchanger to absorb excess heat from a chemical reactor. If the heater fails, tank A will be too cool for the recombination of gas molecules expected, and at the same time, the chemical reactor will overheat as the excess heat fails to be absorbed...The interactions are no longer linear. The heater has what engineers call a ’common mode’ function - it services two other components, and if it fails, both of those ’modes’ fail’.[29]

The above case of the heater is an example of a system characterized by complex interaction. ’Complex interactions are those of unfamiliar sequences, or unplanned and unexpected sequences, and either not visible or not immediately comprehensible’.[30] Of course, the case of the heater is rather simple and in engineering many technical devices have been developed to prevent these kinds of accidents. However, in real life complex systems are far more elaborated. The source of their complexity is not only common mode function, but also proximity and indirect information sources. They are further characterized by unfamiliar or unintended feedback loops, many control parameters with potential interactions and limited understanding of some processes.[31] Further, complex systems may consist of both technological and social subsystems that interact.

Complex systems are not necessarily high risk systems. A nuclear power plant and a government bureaucracy are both complex whereas the former has catastrophic potential and the latter has not. To explain such phenomena Perrow introduces a second variable in his theoretical scheme: tight versus loose coupling.[32]

Systems like nuclear power plants have a high risk potential not only because they have many common mode functions (complex interactiveness), but also because the parts, units and subsystems are tightly coupled. I.e., if something goes wrong it has an immediate effect on other parts of the system. Tight coupling means that there is no slack or buffer between parts, units and subsystems.

Government bureaucracies are also characterized by complex interactiveness. However, here parts, units and subsystems are loosely coupled: there is slack or buffer between them. Because of that, parts of the system can to a certain extent behave independently without having much effect on the whole. In loosely coupled systems slack or buffer creates time in case of emergencies and therewith provide better opportunities to intervene:

> ’Loosely coupled systems ... can incorporate shocks and failures and pressures for change without destabilization. Tightly coupled systems will respond more quickly to these perturbations, but the response may be disastrous’.[33]

If we now combine the two sets of variables - linear versus complex interactiveness and tight versus loose coupling - it is evident that the complex tightly coupled systems are the ones with catastrophic potential and that from the perspective of risk management we would like all our systems to be linear and loosely coupled. However, reality is not as we would like it to be. In modern production systems complex interactiveness and tight coupling cannot be avoided.

Although his book is on the *analysis* of high risk systems, in the last chapter Perrow gives some clues as to risk *management*.[34] He does so by linking central versus decentral authority to interactiveness and coupling. The relations between these variables according to Perrow are depicted in figure 1.

Figure 1: Centralization/Decentralization of Authority Relevant to Crises

		INTERACTIONS *linear*	INTERACTIONS *complex*
COUPLING	*tight*	CENTRALIZATION for tight coupling. CENTRALIZATION compatible with linear interactions (expected, visible). Dams, power grids, some continuous processing, rail and marine transport. 1	CENTRALIZATION to cope with tight coupling (unquestioned obedience, immediate response). DECENTRALIZATION to cope with unplanned interactions of failures (careful slow search by those closest to sub-systems). Demands are incompatible. nuclear plants, weapons; DNA, chemical plants, aircraft, space missions. 2
COUPLING	*loose*	3 CENTRALIZATION or DECENTRALIZA-TION possible. Few complex interactions; component failure accidents can be handled from above or below. Tastes of elites and tradition determine structure. Most manufacturing, trade schools, single-goal agencies (motor vehicles, post office	4 DECENTRALIZATION for complex interactions desirable. DECENTRALIZATION for loose coupling desirable (allows people to devise indigenous substitutions and alternative paths), since system accidents possible. Mining, R&D firms, multi-goal agencies (welfare, DOE, OMB), universities.

Source: Perrow, 1984, p. 332.

Organizations that fit into cell 1 require tight coupling for efficiency reasons. An example is rail transport. Because interactiveness is linear failures can be foreseen and, if they occur, they are visible. The response to disturbances and failures is centralized and carried out top-down. If not, failures could expand over the whole system because of tight coupling.

Cell 2 refers to complex tightly coupled systems. These systems are confronted with inconsistent demands. On the one hand, tight coupling requires top-down centralized leadership in case of crisis. However, because of the complex interactiveness in these systems, unplanned and unexpected sequences may occur that are not visible nor immediately comprehensible. Their very nature implies that reactions to such disturbances cannot be built in the design on beforehand. Therefore, disturbance detection and risk management have to be located on the spot. This calls for a decentralization of the command structure.

Loosely coupled linear organizations (cell 3) embrace most manufacturing and assembly-line production. Here one has a choice between centralization and decentralization. In most cases of industrial production that fall into cell 3, one can however observe centralized authority. Probably this is due to the heritage of Taylorism which is still deeply entrenched in every day management practice. Given the option of choice between centralization and decentralization, in my view decentralization should be preferred from the perspective of both reducing the number of potential disturbances in production as well as the adequacy of risk management.

Finally, the combination of complex interactiveness and loose coupling asks for decentralization. Because of loose coupling, time, resources and alternatives are available to respond to the unexpected which is inherent to complex systems. In such a situation most benefits can be gained if the personnel at the spot is capable and allowed to analyse and to act as it sees fit to prevent disturbances to expand to other parts, units or subsystems.

From Perrow’s analysis we can conclude that because of restricted rationality not all risks or disturbances can be surveyed on beforehand. Consequently, from the perspective of risk management a perfect system design seems to be an impossible goal to achieve. However, if we could manage to reduce complexity and tight coupling in systems, we would be well on the way.

6. The Socio-Technical Contribution to Risk Management

Modern Socio-Technics (MST) relates directly to risk management, especially to risks arising from the complexity of organizations. ’The Dutch approach focuses on the structural architecture of the firm *as a whole*, regarding the *controllability* of the total system as the central problem to be dealt with by the organization.’[35] It offers a solution to the problems of complex interactive and tightly coupled organizations, at least to the extent that MST claims that the effects of external disturbances on the organization can be substantially weakened by organizational re-design. The starting point is the idea that the controllability of a system as a whole is determined by the relationship between control capacity and the need for control. As a norm for total controllability of a system, control capacity divided by the need for control should at least equal 1. Preferably the outcome of this ratio should be larger than 1. The norm of total controllability can be met in three ways: by increasing control capacity, by decreasing the need for control or by both increasing control capacity and decreasing the need for control.

MST offers a wide variety of interrelated techniques and instruments that help to re-design systems in such a way that the norm of controllability is met. In the frame of this paper I cannot elaborate on these. The interested reader is referred to the relevant literature.[36] However, as some of the MST design proposals are directly related to our argument, I will mention these here briefly.

First of all, MST seeks to integrate the functions of control and production. Instead of attempting to integrate control and production as subsystems, MST aims at the integration of control and performance functions. It introduces two concepts. The *control structure* is the allocation and coupling of control functions. The *production structure* is the grouping and coupling of performance functions.[37] MST proposes to reduce the need for control of the production structure by parallellization and by segmentation.

By *parallellization* the effects of disturbances externally induced into the system are reduced. As MST has focused so far mainly on market related production, its treatment of disturbances in this respect mainly relates to external demand variation, i.e. changes in the demand for product mix and volume. Parallellization means that production is organized in parallel independent production lines. After products are clustered on the basis of relevant similarities for each cluster a separate production line is developed. Thus the degree of variation within each line is low, while the variation between lines is large. As a result the total variation that can occur within the production structure as a whole is substantially decreased.[38]

Segmentation reduces the internal variety of production lines by the selective clustering of performance functions into segments with a minimum of interfaces.[39] Instead of the specialization of workers which results in fragmentation of production, segmentation aims at the composition of ’whole-tasks’, i.e. the clustering of performance activities that are logically interdependent and that can logically be separated from other performance clusters at the same time.[40]

Parallellization and segmentation simplify the production structure and induce a decrease of the need for control therewith increasing the controllability of the system as a whole. In terms of Perrow's scheme, the re-design of production systems by applying parallellization and segmentation makes them less complex and less tightly coupled.

Controllability of the system as a whole is further improved by MST because it also aims at increasing control capacity. Here the principle is to organize the control structure in such a way that control and performance activities become integrated to the largest possible extent. In other words, the control function is decentralized. This is done by the formation of 'whole-task groups' that are responsible for the execution of whole-tasks as defined in the production structure. Thus the whole-task group not only performs the production function, but also the function of control (preparation, monitoring, control, external regulation) to the highest possible degree. In this way the gap between performance and control is closed.

An important conclusion one can draw from the MST approach is that decentralization of authority is a major tool to increase the controllability of production systems as a whole. Although MST analysis differs from Perrow's, in their outcomes the two are congruent to a large extent. Perrow's analysis diverges from the MST approach in the respect that MST does not differentiate between dissimilar kinds of production systems, while Perrow does. The MST message is that the controllability of all systems is enhanced by both the integration of control and production as well as decentralization of authority. Perrow, on the other hand, suggests that for linear tightly coupled systems centralization is the best solution and that complex tightly coupled systems need both centralization and decentralization.

We have to mind, however, that MST's aim is to reduce complexity in production systems as well as to make them more loosely coupled. It follows that the implicit claim of MST is that systems which are now according to Perrow in the linear tightly coupled cell and in the complex tightly coupled cell can by re-design be moved into the direction of more linear respectively loosely coupled cells. Further research is needed to investigate which types of tightly coupled linear and complex systems will respond to the MST claim and which types will not.

If the MST claim is true, decentralization of authority and control can be a major contribution to risk management. However, we have to take into account that the emphasis in the analysis of both MST and Perrow is predominantly structural.

From the history of risk analysis and risk management as presented in section two it can be concluded that an analysis of the relationship between risk prevention and human behaviour at shopfloor level sofar is not a central issue in theory and research. An exception to this is the work of psychologists. These, however, mainly focus on individual behaviour and not on social behaviour. True enough, approaches like Perrow's and MST concentrate on formal social system characteristics, but they lack an evaluation of actual social behaviour as it evolves at the shopfloor.

A strong plea for shopfloor level analysis within the frame of formal system characteristics follows from the idea of bounded rationality. The total set of risks can be divided in two subsets. The first subset can be thought of as comprising all risks that are known because of past experiences or as an outcome of such techniques as simulation and gaming. Such risks can be rationally managed by the adaption of policies and organizational structures. The second subset consists of risks that cannot be known. We assume that such risks exist but we are not able to define them, let alone that we can take measures to prevent them to manifest themselves and to grow into crises. Next to just wait and see, the only policy we could follow is to put our trust into the workers at the shopfloor and to hope that they will act adequately once the moment is there.

Related to undefinable risks decentralization of authority to the shopfloor and increasing the substantial rationality of workers seem to be the only sensible options, since we may expect workers to act adequately only if they have the authority to do so and if they have the skills and knowledge. Concerning the latter it is paramount that knowledge and skills are not only defined as technical entities, but also as social knowledge and skills: workers should know how their actions relate to those of others and should be able to communicate and cooperate under conditions of pressure.

From this perspective the MST approach is a promising starting point. By parallellization, segmentation and the introduction of whole-task groups organizational complexity is reduced and the substantial rationality of workers is enhanced. In other words, by MST redesign the number of interfaces in the organization is substantially minimized, authority is decentralized and within whole-task groups workers should have a multi-functional orientation by which their rationality is broadened. Thus MST promotes the detection of risks at their sources, i.e. on the shopfloor, and in an early stage of development. Consequently, risks can be more adequately reacted to. In other words, top-down risk management by centralization and the line of command is substituted by bottom-up risk management that relies on a broadening of workers' knowledge, skills and capacities of taking initiatives if things run out of hand.

From the point of view of risk management, however, MST has three weak points. Firstly, MST is foremost a structural approach. The problem of organizational culture is largely neglected. Structural change by redesign should be accompanied by cultural change to prevent a misfit between structure and culture and to install the basic values in workers in order to enable them to actually use the authority vested in them. It follows that MST could gain if its design prescriptions would also take into account the cultural dimension.

Secondly, although MST reduces the number of interfaces it seems not so much to bother on the interfaces left after the process of re-design is completed. Therefore, it does not answer the question how to deal with risks that originate from the interfaces in the organization and with those that come from sudden vehement crises in the external environment. Both types of risk management seem to call for centralization and reliance on the top-down line of command which is contradictory to our plea for decentralization sofar.

The problem of sudden and vehement crises in the external environment that threaten the very existence of the organization (e.g. collapse of the stock market, strikes in related subcontracting firms, floods, fires, earthquakes, etc.) have a much lower probability than risks emerging from the production process itself. If one has to set one's priorities, it seems therefore wise to focus on production related risk management. Further, even if priority is given to decentralization at the cost of the development of a top-down line of command we may hope that workers initiative and creativity will compensate the lack of centralized coordination to some extent.

The idea that the problem of remaining interfaces can only be solved by centralization is only partially true. Much can be achieved by adequate training and the rotation of personnel. In this way units, groups and subcultures are linked, therewith reducing the risks that may originate from the interfaces between them.

In this respect, a lot can be learned from the Japanese experience. In Japanese firms that work with whole-task groups the interface issue is tackled by training the employee in 'contextual skills' and by elaborate systems of job rotation. Contextual skills are integration oriented. They have to do with the before mentioned capacity to perform different tasks (multi-functionality and flexibility), with a positive attitude to cooperation, with communicative skills, with the quality to adapt to new tasks, with leadership potential, with learning and teaching capacity and with the ability to negotiate in a positive way. Contextual skills are learned by job rotation both within the whole-task group and within the firm as a whole.[41]

A third weak point of MST is its neglect of informal organization. The same holds for the Perrow approach. Both theories emphasize the formal organization and undervalue processes of coordination and mutual adjustment that go on outside the formal authority structure whether the latter is centralized or decentralized. As to MST this is surprisingly since many authors of this school of thought mention as their sources of inspiration studies in which precisely the importance of informal organization is stressed.

The famous study of Trist and Bamforth[42] on the effects of mechanization in British coal mines pointed to the importance of informal communication[43] and the inability of more formal procedures to fulfil the same functions. The Hawthorne experiments showed how powerful such informal organization[44] may be as it regulates production independent of management directives. Likewise Mumford[45] demonstrated the relevance of informal group norms to the quality of task performance. According to Dalton[46] top management is not able to impose regulations against the will of groups lower down the line.

Informal organization is complementary to formal organization. It can be a source of opposition to formal management's policies. At the same time, however, it provides mechanisms of mutual adjustment, alternative channels of communication and social cohesion[47]. As such it overrides the detrimental effects of the formal structure and enhances substantial rationality, i.e. the individual participant's 'intelligent insight into the interrelations of events'[48] occurring in the organization.

Informal organization then can compensate in those situations which were not foreseen in formal design and procedures. This is not to say that management should refrain from improving formal organization and rely completely on informality. Especially not as in many cases informal procedures may be contradictory to formal rules. Neglect of the gap between formal and informal organization may cause a distortion of management's view on reality, leads to irrational behaviour which may turn out to be fatal if things actually go wrong.

In order to achieve the best possible conditions for effective risk management, management additionally must be aware of informal organization, of the social definitions of the situation as they emerge at the shopfloor, to know how informal organization relates to formal organization and to attempt continuously to close the gap between the two.[49] This is an incremental process that develops within the frame of dynamic conditions such as technological innovations, changing markets and institutional arrangements.

In this respect the importance of leadership is clearly demonstrated in a study by Guest[50]. He concluded that the improvement of the organization's performance could be related to management's ability to integrate formal and informal organization. It followed from his study that the more formal and informal organization became integrated the more the number of incidents, of grievances, sickness absenteeism and labour turnover decreased.

7. Risk Management and Complexity in the Chemical Process Industry

Bax empirically explored in the chemical process industry the theoretical perspective on risk management as presented in the foregoing sections.[51] Two chemical plants were compared, ANCEL and NIMIL both belonging to the same parent company, TYRAD.[**] The primary processes of these two plants can both be characterized as complex and tightly coupled and did not answer the criteria of MST design rules. The number of incidents - defined as accidents and near accidents - in ANCEL as measured over a two year period was substantially higher than in NIMIL.

From the theory of formal and informal organization the hypothesis was derived that a negative correlation could be expected between leadership stability and the number of incidents occurring. Adequate leadership in the meaning described in the foregoing section can only be achieved if the manager involved holds his position for a certain period of time both because it takes time for a manager to get to know the informal organization before he will be able to handle it effectively, and because managers too have their personal ways of managing and of interpreting formal rules and procedures. As a result the lower ranks too need time to get tuned to a new management style. Only then management becomes predictable for those to be managed and contributes to an enhancement of substantial rationality for the shopfloor. Consequently, from the above the hypothesis was derived that, ceteris paribus, a negative relationship exists between the stability of organizational leadership and the safety of production processes.

The stability of leadership was defined as the degree to which management *positions* were submitted to changes in management *personnel* over time. Thus, if in department A the position of department manager was fulfilled in one year by one and the same person, while in department B this position was fulfilled in one

[**] ANCEL, NIMIL and TYRAD are fictitious names.

year by two persons, the position of department manager in department A has a higher stability than the same position in department B.

Before continuing to report on the test of this hypothesis, two additional remarks have to be made. Firstly, from the perspective of integrating formal and informal organization effectively, the time factor is a necessary though not sufficient condition. Even if the time needed is available, this does not logically imply that time is actually used to integrate formal and informal organization. Further, next to situational factors, leadership performance is also dependent of the personality characteristics of the managers involved which were outside the frame of the study.[52] Secondly, the relation between leadership stability and safety is not necessarily a linear one. We would rather hypothetically expect to take it the shape of a U-curve: the number of incidents being high when leadership stability is low, then descending and rising again where managers stayed in the same position for a long period of time. The latter could be explained by the effect of routinization of the management job. As only data covering a two year time period were available, we were not able to test for a possible U-curve nature of the relation.

To test the hypothesis of the relation between the stability of leadership and the number of incidents, a regression analysis was made where the total number of incidents per month for both ANCEL and NIMIL is explained by the average duration of time (per month) of leadership positions hold in both plants. The regression was estimated by means of a dummy variable indicating the differences between the plants. The regression equation found was (t-values between brackets):

Y	=	19.18 - 7.6 δ - .33 X;
		(5.35, -5.92 and -2.55)
where:		
Y	=	number of incidents per month;
X	=	average duration in months of leadership positions hold;
N	=	48;
δ	=	0 for ANCEL
δ	=	1 for NIMIL.

The effect of X differed not significantly between the two plants. Only the constant differed significantly between ANCEL and NIMIL: for ANCEL it was 19.18 and for NIMIL 11.62. The adjusted R-square was .63 and all parameters were significant at the 2 per cent level. In separate regressions for both plants the Durban Watson statistic was respectively 1.75 and 2.03; so it can be concluded that there is no problem with autocorrelation.

The above test result indicates that for ANCEL and NIMIL a negative relationship exits between leadership stability and the occurrence of incidents. However, one is left with the difference between the constants of ANCEL and NIMIL. As such the difference found is not surprising since leadership is always executed within an institutional setting that functions more or less as a given. This holds the more for lower management which often lacks the power to change the social configuration of the production processes to a substantial degree.

Given the above we set out to check what differences in the respective conditions could next to leadership stability explain the differences in the occurrence of incidents between NIMIL and ANCEL, the perspective being the ways workers handle the rules and procedures to which they are submitted.

The first factor discovered was the way departmental management was tied to the parent company (i.e. TYRAD). ANCEL's management was fairly tied to TYRAD's bureaucratic hierarchy. Its degrees of freedom of adjusting TYRAD's general safety policy to the specific conditions of ANCEL's primary process were limited. Because the actual locus of control was vested in the higher echelons of the TYRAD organization and the normative dependence of ANCEL was high, the fit between formal norms as to how to behave at shopfloor level on the one hand, and the actual conditions of behaviour on the other, was weak. In such a situation one runs the risk that informal organization is strengthened as opposite to formal organization. Contrary to ANCEL, NIMIL management succeeded to formulate a safety policy of its own adjusted to the specific conditions of NIMIL's primary production process. Part of this policy was the attempt to let the workers internalize the norms of the safety and quality of the work done. Actually, thanks to its relative autonomy NIMIL management was able to close down the gap between formal and informal organization to a substantial degree.

The second factor related to safety was the geographical dispersion of the installations that were part of the technology of the respective primary production processes. ANCEL's installations were widely spread over a large area. On the one hand, this induced looseness of coupling between the installations, but it also increased the complexity as it made it more difficult for operators, supervisors and management to get an overview. The fact that the authority structure within ANCEL was decentralized, was therefore more dependent on the spacing of the installations than on the nature of the technology that made up the individual installations.

The effects of decentralization induced by geographical spacing were manyfold. To mention the most important ones: Geographical spacing prevented management supervisors to be frequently on the spot where the action was. Information was second or even third hand. There was a substantial delay in the processing of information due to distance. Management was unable to exert effective control and thus could not check to what extent official and formal rules were effective. Thus, even if ANCEL's management would have had the leverage to adjust TYRAD's safety procedures to the specific conditions of the ANCEL production process, they probably would not have known in what direction such adjustments should go. It is easy to see that this situation only aggravated the more leadership stability decreased.

The conclusion drawn from the study in the chemical process industry is that for the two plants investigated and which can be characterized as complex and tightly coupled the degree of complexity and of tightness of coupling as such do not produce a sufficient explanation of the differences between the two plants as to the number of incidents occurring. The research suggests that adding to Perrow's scheme variables such as leadership stability, the degree of plant management's autonomy viz-à-viz the larger company, the effects of organizational culture at shopfloor level, the nature of the interfaces between shopfloor and higher levels in the organization and the geographical dispersion of the plant's production processes could be a fruitful perspective.

8. The Future of Risk Management: Some Conclusions

Industrialization meant an enlargement of scale of production and therewith a growth of the complexity of production processes. In Western industrialized countries these processes accelerated after World War II.[53] This article did not so much focus on the effects of growing complexity in society as a whole, as well as on production related risks evolving from the increased complexity of primary production processes.

In the 1960's in US production enlargement of scale and growing complexity led to a growth of the number of risks as well as to an increase of their effects in terms of damages. Consequently, American firms were confronted with rising insurance premiums and even with refusals by insurance companies to insure certain risks. At present a likewise trend can be observed in the Netherlands too. Next to this, governments tend to privatize social security as a result of which the effects of risks at the shopfloor level have to be accounted for by the employer. In the Netherlands this holds especially for sickness and the negative health effects of the conditions of working life.

The rise of insurance premiums forced US firms to employ insurance or risk managers, managers responsible for the control of the insurance portfolio. Thus risk management became associated with risk assessment and risk-benefit accounting. The more insurance premiums rose and risks became uninsurable, the more the content of risk management shifted from accounting to prevention.

From its origins onwards risk management deals primarily with complexity. In the foregoing sections we emphasized how an ever progressing division of labour led to an increase of functional rationality and a decrease of substantial rationality. This self sustaining mechanism of the so-called vicious circle of bureaucracy weakens the controllability of production processes to a substantial degree and can be associated with a strong belief in the issuing of formal rules and procedures in order to master complexity and the related risks. However, as we stated before, for the actor the promotion of functional rationality leads to a loss of overview and to ritualism and thus affects the competence of workers required for effective risk management.

It is remarkable that the history of the risk management profession too developed along the lines of a progressive division of labour and an increasing specialization and is presently negatively affected by these. The study and teaching of risk management is spread over different disciplines. In organizations this specialization is often institutionalized in different subdepartments each one taking account of a different type of risks. As a result the interrelations between risks are neglected and the question arises who manages the specialists. The solution to this problem may be the introduction of interdisciplinary oriented general risk managers who are able to provide the overview needed.

Further, it is rather peculiar that among the specialists engaged in risk management an active interest in the social and organizational conditions of task performance sofar is lacking. I.e., specialists that take an active interest in the relation between human labour and risk tend to concentrate on the effects of production processes on the worker. In this tradition stand issues like the impact of technology on the quality of working life, the effects of technology and organization on health and so on. In these cases risk is defined as an entity produced by the production process affecting workers. Starting from the idea that people make mistakes and that many of these are of a systematic nature in the sense that they logically follow from the ways production processes are organized, risk management should put more emphasis on organization as a factor explaining human failures.

A third remark to be made is that risk management today is rather limited. It attempts to assess risks and to develop measures aimed at prevention. This approach mostly evolves within the boundaries of the prevailing organizational structures therewith neglecting organizational complexity as one of the major sources of risks. Modern risk management could certainly gain if it would incorporate a more design oriented perspective focused on the reduction of organizational complexity.

In the foregoing we referred to Perrow’s theory on the catastrophic potential of organizations as an approach that relates risk to the characteristics of organizational structures. Perrow distinguishes two variables that determine an organization's catastrophic potential: interactiveness and coupling. Especially production which is complex interactive and tightly coupled should be considered to be dangerous. Research in the chemical process industry pointed to the fact that Perrow's analysis is still rather rough. A a number of intervening variables were found which explained the different ways workers reacted to complexity. Among these were such factors like the stability of leadership, organizational culture, the structuring of the relation between the shopfloor and higher echelons in the organization and geographical spacing. Within the context of complexity these factors contributed to the explanation of differences in the occurrence of incidents. Although these findings should be considered to be of a preliminary nature they offer a fruitful perspective for future research and a further elaboration of a theory of risk in which emphasis is laid on the relation between organizational characteristics and the behaviour of workers on the shopfloor.

Dutch Modern Socio-Technical theory (MST) seems to offer solutions for some of the dilemmas presented before. It is a design oriented approach aimed at the reduction of the complexity of production processes and the enhancement of control. By re-designing the control structure in such a way that the power to control is laid down as low as possible in the organizational hierarchy the management of risks is substantially improved. By the instalment of autonomous task groups the substantial rationality of the individual worker is enhanced.

However, from the point of view of effective risk management MST in its present state has two weak points. Firstly, although by parallellization and segmentation it reduces the number of interfaces in the production organization substantially, it seems to be not so much concerned as to the limited number of interfaces left after re-design. Secondly, MST is predominantly a structural approach. Sofar it lacks an active interest in processes of cultural change to be associated with the re-design of production structures.[54] These criticisms do however not imply a rejection of MST, but should rather be considered to be a plea for a further elaboration to increase its power as a contribution to effective risk management.

From the foregoing sections it became clear that modern risk management has everything to do with the design of organizational contexts in order to reduce the probability of disturbances in production processes. We have shown that as such it is closely related to the study of the conditions of work to the extent that the latter largely determine the occurrence of human failures. In turn, organizational and technical conditions of production processes themselves can affect the safety, wellbeing and health of workers.[55] Although risk management in the meaning of controlling human failures is up till now a scientific domain separated from that of the improvement of the quality of working life, both can gain if future research manages to treat them as interrelated fields.

As risk management essentially means the prevention of undesired events to happen, quality management can be defined as a specific type of risk management by which low quality is the issue to be prevented. It is remarkable that some of the dominant quality systems of today, notably ISO, seem to suffer from the same weaknesses as traditional risk management. In most ISO approaches one heavily relies on the issuing of formal rules and procedures in order to control human behaviour without challenging the prevailing power structure of the organization. Therefore, it seems that the prevailing approach to quality management can learn some lessons from the experiences in other domains of risk management.

Finally, as the fields of quality management, of the health and safety of workers and of production risks are so interrelated and have so much in common, it may be fruitful to integrate them more closely in the future. Actually, presently in Belgium promising experiments have been directed to the development of one integrated care system[56] covering all three types of risks.

Notes

1. This definition is derived from Merkhofer, 1987, p. 2.
2. J.E. Bannister and P.A. Bawcutt, 1989, p. 4.
3. Claes & Meerman, 1991, p. 4.
4. Doherty describes these developments as a trend ’from insurance management to the more general risk management’. See N.A. Doherty, 1985, p. 5.
5. Bannister and Bawcutt, 1989, p.177.
6. J.L. Bouma, 1990, p. 111.
7. H.A. Simon, 1976, ch. 4.
8. Essinger and Rosen, 1991, p. 31.
9. Next to the decision making process psychologists also studied the ways how risks can evolve from the different ways the decisions taken are implemented, for example, the effects of different patterns of communication and the sources of human errors. See B.A. Turner, 1978 and W. Wagenaar, 1989.
10. March and Shapiro, 1978.
11. MacCrimmon and Wehrung, 1986.
12. Zhores A. Medvedev, 1990. Notably the first part of this book.
13. In his analysis of the flood that in 1953 fell upon the Netherlands Kees Slager also mentions that poor communications, a compartmentalization of specialists, long hierarchical lines and a lack of understanding by those in charge prevented an adequate reaction. See Kees Slager, 1992.
14. Berting, 1992, p. 50.
15. Berting, 1992, pp. 51-52. See for an extensive treatment of this subject also Bax, 1990, pp. 7-35.
16. The relevant works of these authors are mentioned in the bibliography.
17. See Mannheim, 1940, pp. 53-54.
18. Weber, 1972, pp. 12-13.
19. Elsewhere I elaborated on this theme. See Bax, 1990, pp. 7-35.
20. Mannheim, 1940, pp. 58-59. This process of social development induces feelings of fear and alienation in individuals which in Western Europe were compensated for by the rise of mass movements in the 1920’s and 1930’s. Although the attractiveness of mass movements is clearly a phenomenon of the past, I think that Mannheim’s thesis is still valid. Nowadays the lack of substantial rationality is mainly compensated for by the rise of religious sects, of psychiatric treatment, by drug abuse and alcoholism and by

hooliganism. See for a sharp description of the social functions of hooliganism: William Buford, 1990.

21. De Sitter, 1989; De Sitter and Den Hertog, 1990; Van der Zwaan, 1991.
22. See Wagenaar, 1989.
23. Merton, 1968, p. 253.
24. See also Gouldner, 1954.
25. See Van der Zwaan, 1991: 142-144; Bax, 1992: 67-68.
26. Ackoff, 1981.
27. Perrow, 1984.
28. Perrow, 1984, p. 78.
29. Perrow, 1984, pp. 72-73.
30. Perrow, 1984, p. 78.
31. Perrow, 1984, p. 86.
32. Perrow, 1984, pp. 89-94.
33. Perrow, 1984, p. 92.
34. Perrow, 1984, pp. 329-335.
35. De Sitter & Den Hertog, 1990, p. 5.
36. De Sitter and Den Hertog, 1990; Kuipers and Van Amelsvoort, 1990.
37. De Sitter and Den Hertog, 1990, p. 14.
38. De Sitter and Den Hertog, 1990, pp. 16-17.
39. De Sitter and Den Hertog, 1990, p. 18
40. Van der Zwaan, 1991, 165-166.
41. Aoki, 1988, p 50.
42. See Trist and Bamforth, 1951 and also Trist, Higgin, Murray and Pollock, 1963.
43. See also Barnard, 1962.
44. Following Roethlisberger and Dickson we define informal organisation as the actual personal interrelations existing among the members of the organisation which are not represented by, or are inadequately represented by, the formal organisation. See Roethlisberger and Dickson, 1950, p. 566.
45. See Mumford, 1959.
46. See Dalton, 1959.
47. See Barnard, 1962, chapter 9.
48. Mannheim, 1940, p. 53.
49. Already in 1954 Gouldner analyzed the relations between leadership and formal and informal organization. He discerned three types of bureaucracy of which ’representative bureaucracy’ is the one in which formal and informal authority go together. See Gouldner (1954).
50. See Guest, 1962-a and 1962-b.

51. Bax, 1995.

52. So we abstain from more psychological models like Fiedler's contingency theory and cognitive resources theory in which personality traits and group performance are related, mediated by the situation. See Fiedler, 1967 and 1978 and Fiedler and Garcia, 1987.

53. In my book on the modernization of Dutch society I analyzed these processes as they developed in the Netherlands. See E.H. Bax, 1990, pp. 35-72 and pp.147-152.

54. Elsewhere I analyzed the relation between structural and cultural change and put forward the view that structure, culture and technology are closely related. See Bax, 1991.

55. In the Netherlands this is one of the crucial elements in the Law on Working Conditions (ARBO) which aims to improve the safety, the health and wellbeing of workers.

56. Here we refer to the Pellenberg Audit System (PAS). However promising, a disadvantage of this system seems to be that with its reliance on formal procedures it looks similar to the ISO approach. See Heselmans e.a., 1994.

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